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5. Such a change of radial velocity is a necessary consequence of a velocity distribution (for the peculiar motions) different from that given by Maxwell's law.

6. A first approximation to the velocity distribution has been derived for the *K* stars. It explains the change of velocity with proper motion in a satisfactory manner.

7. Some positive indications have been found of a change of radial velocity with absolute magnitude, the brighter stars moving more slowly than the fainter stars.

[1] *Lick Obs. Bull.*, 7, 113 (1913).

[2] See *Annals Harvard Coll. Obs.*, vol. **50**.

[3] Adams and Kohlschütter, "Some special criteria for the determination of absolute stellar magnitudes," *Contrib. Mt. Wilson Solar Obs.*, No. 89; *Astrophys. J.* **40** (1914).

[4] For example, *Astrophysical Journal*, **31**, 266 (1910).

[5] Kapteyn, *Monthly Notices*, 72, 743 (1912).

[6] Eddington, *Observatory*, 34, 355 (1911).

[7] *Proc. Amsterdam Acad. Sciences*, 14, 524 (1911).

[8] Schwarzschild, *Astron. Nachr.*, No. 4557 (1912).

[9] See *Publ. Astron. Lab. Groningen*, No. 11, p. 12.

CRITIQUE OF THE HYPOTHESIS OF ANOMALOUS DISPERSION IN CERTAIN SOLAR PHENOMENA

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According to the theory of anomalous dispersion, the interpretations of solar observations in terms of absorption, motion, pressure, and level are generally misleading since the observed phenomena, such as prominences, flash spectra, flocculi, and displacements of the Fraunhofer lines are from this point of view mainly the effects of anomalous refraction in the solar atmosphere, so that in their study we are facing optical illusions. The establishment of such a point of view would revolutionize or render futile many of the present lines of solar and stellar observation, and would make practically impossible the solution of many problems which confront the investigator. It is therefore of the highest importance to determine the form and extent of the influence of anomalous refraction in the solar atmosphere, if it obtains to a detectible amount.

There is a degree of vagueness in the deductions from the theory, due to its extreme flexibility, that makes a quantitative examination of its claims difficult. During the present year, however, W. H. Julius, its originator and chief supporter, announced a deduction that offers an opportunity of making such a quantitative test, namely: the mutual influence of Fraunhofer lines upon each other.[1] The observational data available for a crucial test are available,[2] and consist of the displacements of 506 Fraunhofer lines at the edges of the penumbra of eccentrically located sun-spots observed by me. In such observations the slit of the spectrograph is parallel to the radius of the solar image passing through a spot whose position for best observation is between the limb and the midpoint of the radius. The displacements are a maximum at the peripheral edges of the penumbra. At the edge directed toward the limb they are in general in the direction of longer wave-length, while at the edge directed toward the center of the disk they are in the direction of shorter wave-length. These displacements were interpreted by Evershed and myself as effects of motion in the line-of-sight, but are considered by Julius to be due to anomalous refraction.

In this phenomenon the particular form in which mutual influence would manifest itself is that a weak line on the violet side of and near to a stronger line is displaced less, but, if on the red side, more than the average amount. Julius, in making the announcement of the deduction to which reference is made, gave a discussion based upon a portion of the available data and obtained a result apparently confirming the deduction and considered by him a veritable proof of the theory. In fact, the deduction follows so directly from the theory that its confirmation would greatly strengthen the position of the theory as a working hypothesis, while a failure of confirmation would discredit it. The questions raised by Julius are elsewhere considered by me in detail.[3]

These displacements are well suited for a definitive test of the theory, as they are purely differential and free from possible observational bias, since they were made without any knowledge of what they are now used to prove. Moreover, a large number of other lines present upon the same plates are available for standards of reference. It is evident that much depends upon the derivation of these standards.

The 506 lines in my original paper do not form a homogeneous series of observations. From this it follows that standard displacements for different spectral regions cannot be determined with high precision by deducing them for each region by any smoothing-out process involving the results for all the segregated regions. There are six series:

(1) λ 3624 – λ 3724; (2) λ 3879 – λ 4410; (3) λ 4634 – λ 4829;
(4) λ 5123 – λ 5349; (5) λ 5598 – λ 6065; (6) λ 6393 – λ 6643.

The measurements represent with high precision the relative displacements in any single region; but the data are not sufficient to obtain the relation between the absolute values for the separate regions to the same degree of precision, depending as they do upon varying observational conditions.

To obtain residuals capable of representing any systematic behavior of lines within the refractive influence of stronger lines, the standard displacements should be derived from the limited homogeneous series of observations in which they are to be used and, as far as the data permit, they should refer to the particular element under consideration. Such standard displacements have been obtained by determining the mean displacements for the lines of each element of a given intensity for each of the homogeneous series.

With these standards the displacements of 131 Fraunhofer lines within 0.5 A of stronger ones are compared, 67 on the violet side of stronger lines and 64 on the red side. The hypothesis of mutual influence requires that for the lines to the violet the mean residual be negative and for the lines to the red, positive. The result of the comparison applied to this large number of lines is that 67 lines to the violet give a mean residual − 0.0003 A, and 64 lines to the red give a mean residual − 0.0004 A.

Stated in another form, the sum of the favorable residuals is 0.212 A; of the unfavorable, 0.218 A. Tested, then, by standards deduced from the homogeneous series of observations to which they are to be applied, the lines under the influence of stronger ones show no systematic difference within the limits of measurement from lines not so situated.

Another criterion is whether the effects produced by the influencing lines depend upon their power to produce anomalous dispersion in the laboratory. A comparison of the residuals given by lines under the influence of those having strong anomalous dispersion with the residuals given by others under the influence of lines having very weak anomalous dispersion shows no greater effect in one case than the other.

It would seem that the effect of mutual influence must increase with nearness of the influenced line to the controlling line. The change should then be especially manifest for those in the near neighborhood of such powerful lines as H, K, and 4226.9 of calcium and the strong aluminum lines, all of which show large anomalous dispersion in the laboratory and are bordered by broad shadings or wings in the solar spectrum. From the point of view of the anomalous dispersion theory, these wings are considered dispersion bands. In making the original series of measures, the lines near these very strong lines were in general omitted from the observing list, as they present special difficulties. A few of the best plates have now been remeasured with the view of obtaining data relative to such lines, and also a few plates of a new series of observations on spots belonging to the approaching spot-maximum. The displacements of 144 lines have been measured; of these 16 are within one angstrom of very strong lines showing great anomalous dispersion. For standards of reference the mean displacements for all lines of a given intensity are used. Within one angstrom of these strong lines there are eight lines to the violet which give a mean residual of + 0.0006 A based upon 51 measures, and eight lines to the red which show a mean residual of + 0.0003 A based upon 62 measures. The result is practically zero. There is, moreover, no systematic variation, as the influencing lines are approached from a distance of five angstroms to their near neighborhood.

The displacements so far considered are of lines in the reversing layer and indicate an outflow from the spot-vortex tangential to the solar surface. The important chromospheric lines, H and K of calcium, the hydrogen lines, the D lines of sodium and the b group of magnesium, give displacements of the opposite sign, interpreted as inflow of the high level vapors. Up to the present the theory of anomalous dispersion has not been able to suggest an explanation of these negative shifts.

All these displacements are obtained with the slit of the spectrograph parallel to the radius of the solar image passing through the spot. Displacements of the high level lines are also found when the slit is normal to the radius, which on the line-of-sight interpretation indicate vortex motion. These displacements have always been troublesome to the dispersion theory and are disposed of as occasional phenomena due to unequal refraction at the opposite edges of spots under exceptional conditions. The displacements are, however, a practically constant feature of all spots, persist for many weeks, and characterize regular spots during at least the greater part of their existence.

It is probably possible to imagine a density distribution capable of explaining these displacements, "Since almost any peculiarity in the appearance of spectral lines may be explained by anomalous dispersion, if only we are at liberty to assume the required distributions," as Julius remarks; but it seems questionable that such an artificial condition characterizes a regular spot and the mind accepts more readily the obvious explanation based upon motion in the line of sight.

There is one more consideration bearing upon an explanation of these displacements based upon the anomalous-dispersion theory, namely, the differences characteristic of the elements. In examining the standing of a theory, facts that cannot be explained by it are of particular interest. The existence, then, of such differences becomes of great importance, since as yet it has not been possible to suggest an explanation of them in harmony with the dispersion theory. As standards of reference the displacements of the iron lines of like solar intensity measured upon the same plates have been used. The residuals (that is, displacement for the element minus the mean displacement of iron lines of the same intensity) are given in thousandths of angstroms in the accompanying table:

Element...............	Ba	Ce	Cd	La	Nb	Nd?	Pb	Yt	T
Number of lines........	2	1	1	9	1	3	1	1	47
Atomic weight.........	137	142	112	138	94	144	207	173	48
Mean residual in 0.001A.	+5	+7	+5	+2	+10	0	+6	+6	−3

The residuals for the group of heavy elements are systematically positive and are undoubtedly real, while the residuals for titanium are systematically negative and likewise exceed the errors of measurement.

The displacements considered in this paper may all be interpreted in terms of motion and level as shown in contributions already published.[4] The purpose of the present discussion has been to show their bearing upon the theory of anomalous dispersion in its application to certain solar phenomena of which the theory has suggested partial explanations and to which it has appealed for evidence of its influence in the solar atmosphere. The only quantitative criterion, mutual influence, fails to confirm the theory, and in my opinion there are well established results of these observations for which the theory has no explanation.

[1] W. H. Julius: Radial motion in sun-spots. *Astrophys. J.*, **40**, 1 (1914).

[2] *Contrib. Mt. Wilson Solar Obs.*, No. 69.

[3] Ibid, No. 93.

[4] Ibid, Nos. 69 and 74; *Astrophys. J.*, **37**, 322 (1913); **38**, 341 (1913).